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Search for TeV transient gamma-ray sources of the northern sky using the Tibet- III air shower array

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The Tibet III air shower array has a wide field of view greater than one steradian and a high duty cycle. Using the Tibet III (Nov. 1999 - Oct. 2004) data, we search for TeV transient gamma-ray point sources on the time scale of 120 days, 30 days, 10 days and 3 days. No new source was found at sufficiently high significance on any time scale in the field of view during the live time. The 90% confidence level upper limits on the integral flux above 3 TeV assuming an energy spectrum of $E^{-1.6}$ and of $E^{-2.0}$ are obtained.

1. Introduction

The first detection of a transient emission of TeV gamma rays from Markarian 421 was made in 1992 by by the Whipple group using an Imaging Atmospheric Cherenkov Telescope (IACTs) [1]. The Tibet air shower array had also successfully detected transient gamma-ray emissions from active galactic nuclei (AGN) Markarian 501 in the flare state of 1997 [4], and Markarian 421 in 2000 through 2001 [5]. IACT groups have observed transient emissions of TeV gamma rays from blazar type AGNs such as Markarian 421, Markarian 501, 1ES 1959+650 and PKS 2155–304. Overall spectra of blazars have two broad continuous peaks; the lower-energy peak between infrared and X-ray is attributed to synchrotron radiation from accelerated high-energy electrons in the AGN, and the higher-energy peak between GeV and TeV is attributed to the inverse Compton scattering of the same electrons off the soft photons. And it is known there is a good time correlation between TeV emission and X-ray radiation in a flare state. The observed fluxes of TeV gamma rays of some AGNs show variability on the time scales of months, days, and hours [7]. In addition, there is a report on TeV gamma-ray observation from the variable X-ray binary star Cen X-3 [2]. Recently, the HESS group found a new transient gamma-ray source PSR B1259–63, which is a binary pulsar [8]. The flux was found to vary significantly on the time scale of days correlated with the transient un-pulsed radio emission at 1.4 GHz. Observation of transient TeV gamma rays with other multi-wavelength observations is important to study the physics of TeV sources. Also an "orphan" gamma-ray flare that was not accompanied by an X-ray flare was found from TeV brazar 1ES 1959+650 [6]. It could be expected that such orphan gamma-ray flares may be found more in the future. Therefore, it is interesting to search for such flare sources in the TeV gamma-ray region independently of X-ray flares. Though there exists a wide-field of view survey in the X-ray region by the RXTE satellite, no such search has been done in the TeV gamma-ray region yet. With the Tibet air shower array having a wide field of view and a long-term continuous observation capability, a search for transient TeV gamma-ray sources is done in the northern hemisphere during the observation period for approximately five years.

2. Observation

The Tibet-III air shower array (22,050 m^2), consisting of 533 scintillation counters which are placed at a lattice with 7.5 m spacing, has been operating since 1999 at Yangbajing in Tibet, China (90.522°E, 30.102°N) at an altitude of 4,300 m above sea level, an atmospheric depth of 606 g/cm^2. The details of the Tibet-III array is found elsewhere [4]. The trigger rate is about 680 Hz at a few TeV threshold energy and the average dead time is estimated to be 11%. We collected 6.1×10^{10} events during the period from November 17, 1999 through October 10, 2004, corresponding to 1041 live days. After some data selections, 1.5×10^{10} events remained for further analysis. The mode energy of air shower events is estimated to be about 3 TeV and the angular resolution is estimated to be 0.9° above 3 TeV.

3. Data analysis

In this analysis, the same selection criteria as employed by Method I in the northern sky survey's analysis (Amenomori et al. 2005)[9] is adopted. The sky is divided into $0.1° \times 0.1°$ cells, from $0°$ to $360°$ in Right Ascension (R.A.) and from $0°$ to $60°$ in Declination (Decl.). The number of on-source events is counted with a circular window of radius 0.9° centered at each cell. The background is estimated by the number of events averaged over off-source cells with the same angular radius as on-source, at the same zenith angle, recorded at the same time intervals as the on-source cell events. This method is called "equizenith angle method". This method can eliminate various detection biases caused by instrumental and environmental variations. The Tibet III array, however, has a small anisotropy of $\pm 1.5\%$ at the maximum amplitude in the azimuthal direction, as the array is constructed on the ground with a slight slope of 1.3° to the normal plane in the northwest direction. Hence, we use 35 different dummy source cells that follow the same diurnal rotation (at the same declination) as the on-source cell to correct the effect of anisotropy in the azimuthal direction [9].

To search for transient TeV gamma-ray sources, the observation period of five years is divided into about 120-day, 30-day, 10-day and 3-day subperiods, the numbers of divided data become 11, 38, 116, 372 sets, respectively. When the data-taking system was stopped for the maintenance of observation system and other reasons, live time of some subperiods is not long enough. In the cae that a subperiod has live time shorter than the half of the length of corresponding subperiod, the subperiod is not used for our analysis.

4. Results and discussions

The significance distributions from all directions are shown in Figure 1. All the plots in Figure 1 are consistent with a normal Gaussian distribution. It indicates that no new source was found at sufficiently high significance on any time scale in the northern hemisphere during the observation period through this analysis. In order to avoid missing possible excess events of a flare when the data is split between subperiods, the analysis was done for each subperiod except for the 3-day subperiod by sliding the search window by one-third of each subperiod.

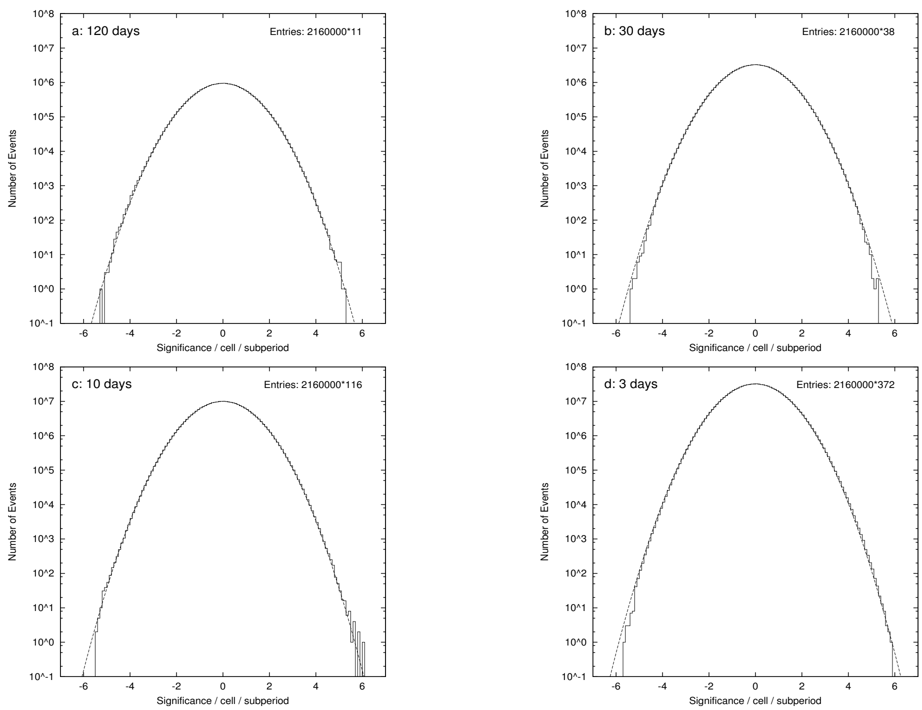

Figure 1. The significance distribution of all directions on the sky map. Approximate time interval: (a) 120 days; (b) 30 days; (c) 10 days and (d) 3 days. It should be mentioned that not all directions are statistically independent as the amount of time shift and window bin shift are smaller than the angular resolution. The solid lines in these figures are derived from all cells defined in analyses. The dashed histograms represent a normal Gaussian distribution.

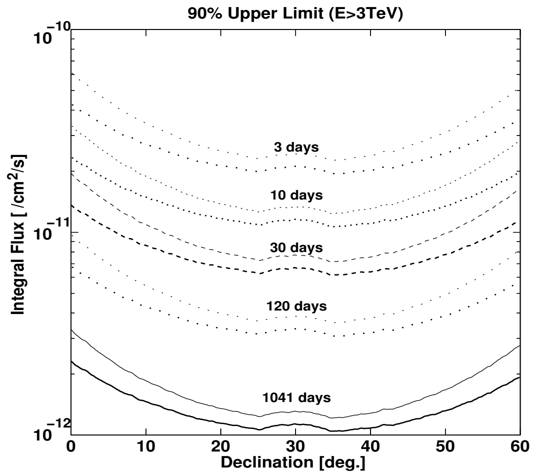

Figure 2. R.A. direction averaged 90% CL upper limits on the integral flux above 3 TeV with an energy spectrum of $E^{-1.6}$ (lower line) and $E^{-2.0}$ (upper line).

Therefore, there is no evidence for new transient point sources $>$ 3 TeV in the celetial band ($0^\circ < \mathrm{R.A.} < 360^\circ$, $0^\circ < \mathrm{Decl.} < 60^\circ$) on the time scales 120, 30, 10 and 3 days.

For reference, R.A. direction averaged 90% confidence level (CL) upper limits on the integral flux above 3 TeV assuming an energy spectrum of $E^{-1.6}$ and $E^{-2.0}$ are obtained in Figure 2. On the time scale of 30 days, a typical flux upper limits at 90% confidence level on the gamma-ray flux assuming the integral spectrum $E^{-1.6}$ are obtained between $6.2 \times 10^{-12}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and $1.4 \times 10^{-11}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ above 3 TeV corresponding between 2 and 5 crabs depending on declination 36° and 60°, respectively. This is the first northern sky search for transient TeV gamma-ray point sources on the time scale of months and days.

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